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3D wrist imaging – Is it time for superman to retire?

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ABSTRACT

Objectives: Computed tomography (CT) of the wrist may be challenged, due to patients' inability to extend the arm for a "Superman pose" resulting in increased radiation dose due to scatter. Alternative positions and less dose administering modalities such as 3D Cone-beam CT (CBCT) and single-shot CT could be considered. This phantom study aimed to estimate scatter radiation dose in different phantom positions using helical and single-shot CT and 3D CBCT.

Material and Methods: Wireless electronic dosimeters attached to the head and chest of an anthropomorphic phantom in various clinically relevant positions were used to measure scatter radiation. In helical CT, the following positions were used: Superman pose, semi-superman pose, wrist on the abdomen, and single-shot CT with the patient sitting in front of and behind the gantry. In 3D CBCT, the phantom was in a supine position with the arm extended laterally.

Results: Helical CT using the Superman pose resulted in a total scattered radiation dose of 64.8 μGy. The highest total dose (269.7 μGy) was obtained with the wrist positioned on the abdomen while the lowest total dose was achieved in single-shot CT with the phantom sitting behind the gantry with the forearm placed inside the gantry (3.2 μGy). The total dose in 3D CBCT was 171.1 μGy.

Conclusion: The commonly used semi-superman and wrist-on-abdomen positions in CT administer the highest scattered doses and should be avoided when either single-shot CT or 3D CBCT is available. Radiographers should carefully consider alternatives when a patient referred for wrist CT cannot comply with the Superman position.

Keywords: Distal radius, Fracture, Computed tomography, Radiography, Cone-beam computed tomography, Radiation dose

INTRODUCTION

The distal radius is one of the most commonly fractured bones in the human body,[1,2] and planar X-ray is the first line of radiographic imaging applied for detecting fractures. However, a wrist fracture is a multifaceted injury ranging from non-displaced to comminute with or without intra-articular involvement.[3] Extra-articular, non-displaced fractures can be treated conservatively with a cast. Substantial variance in planar radiographic measurements characterizing fracture displacement has been reported,[4,5] hence, in equivocal cases or if the fracture displays severe mal-alignment and/or involves the articular surface, a computed tomography (CT) scan can visualize fracture pattern, particularly rotational malalignment, and aid in the treatment decision.

Based on the severity of the injury, CT may be used as a pre-surgical planning tool.[6]

A CT scan, however, entails more radiation dose than radiographs, not only to the wrist and forearm but also to the surrounding body, as a result of scattered radiation. The patient can be positioned in different ways in the scanner depending on physical ability and the extent of the injury. Depending on positioning, patient dose, and scatter radiation may vary. Scattered radiation has been shown to vary between multi-slice CT, cone-beam CT (CBCT), and 4-view radiography of the scaphoid.[7]

Patient positioning commonly used for CT of the wrist is called the "Superman pose," with the patient in a prone position and the affected arm fully extended above the head. The "Semi-Superman pose" is when the arm is extended as much as possible in the elbow, resulting in the arm being positioned close to the patient's head. If the patient is unable to lie down in a prone position, a supine position with the arm resting on the abdomen can be used, which increases the radiation dose as the X-rays need to penetrate the whole body. This practice might not be the best practice but the only option for some patients, due to their physical limitations. With the new wide detector CT scanners, that have become available recently, it is possible to use a single rotation also, called Single-shot CT, where no scout is used before the scan. In this position, the patient is placed beside the scanner, using the laser lights, and the arm resting on the table allowing for wrist CT acquisition in one rotation without the helical movement of the scanner table and the over-ranging associated with a helical scan.[8]

A 3D CBCT using a twin robotic X-ray system has been shown to provide image quality of the elbow superior to that achieved using a multi-detector CT.[9] Wrist imaging using the 3D CBCT has also been shown to provide diagnostically suitable image quality at a lower dose compared to multi-detector CT.[10] For a 3D CBCT scan, the patient is in a supine position, the arm is extended away from the trunk, and the hand rests on a support table mounted on the side of the table.

Image quality has been shown sufficient using both modalities and they are both used in daily clinical practices. Hence, differences in radiation dose may be considered when choosing a modality.

Accordingly, the objectives of this study were to estimate and compare scatter radiation dose to the patients undergoing wrist imaging using the following patient positions and modalities:

1) Superman pose (CT) – the reference position
2) Semi-superman pose (CT)
3) Wrist on the abdomen (CT)
4) 3D CBCT
5) Superman pose (Single-shot CT)
6) Patient sitting behind gantry (Single-shot CT)
7) Patient sitting in front of the gantry (Single-shot CT).

MATERIAL AND METHODS

In this experimental phantom study, scatter radiation to the head, chest area, and ovaries was compared for different patient positions when obtained by helical and single-shot CT and 3D-CBCT of the wrist using an anthropomorphic phantom. Image quality was not assessed in this study, because both modalities are used for wrist examinations in daily clinical practices. Ethical approval was not required, given the experimental nature of the study using a phantom.

Phantom

An anthropomorphic whole-body phantom (Erler-Zimmer GmbH and Co, Lauf, Germany) was used for all CT acquisitions [Figure 1]. The phantom is designed to meet specific criteria regarding positioning training, such as real human bones and a realistic and flexible anthropomorphic exterior plastic shell well-suited for simulating a clinical examination. The phantom weighs 9.5 kg and has a height of 155 cm.

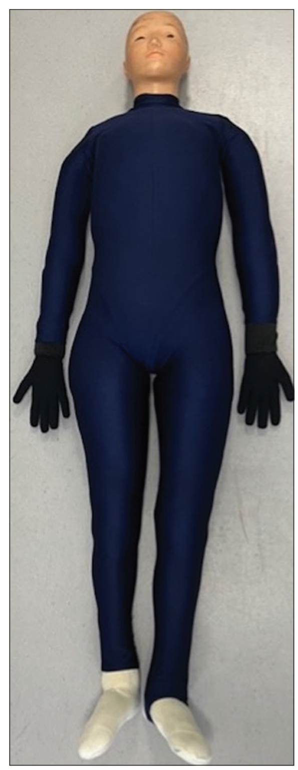

Figure 1: Anthropomorphic phantom with natural human bones and flexibility of joints to meet specific criteria regarding positioning.

Dose measurements

Raysafe I[2] wireless electronic dosimeters (Fluke Medical, Cleveland, US) were used to estimate scatter radiation. Dosimeter reliability regarding linearity, dose-rate dependence, angular dependence, and reproducibility was demonstrated by Inaba *et al.*[11] Before the acquisition, the dosimeter equipment was reset, and electronic devices such as mobile phones were removed from the examination room to avoid interference.

The dosimeters were positioned on the phantom in the following anatomical regions: The glabella, above the right ear, the thyroid, mid-sternal at the level of the xiphoid, the midsagittal plane of the chest on the right side, at the level of the xiphoid, and the ovaries [Figure 2]. Dosimeters were strictly positioned outside the path of direct radiation.

Phantom positioning

In helical CT, the following patient positions were used:

- Superman pose: Prone position and arm extended above the head
- Semi-superman pose: Prone position, arm bent, and wrist adjacent to the forehead
- Wrist on the abdomen: Supine position and arm bent.

Single-shot CT was performed with the patient sitting in front of and behind the gantry and a Superman pose while 3D CBCT was performed with the patient in a supine position with the arm extended laterally. All positions used reflect clinical practice and are visualized in [Figures 2 and 3].

Figure 2: Phantom positioned for a 3D cone-beam computed tomography (CBCT) with dosimeters placed at the glabella, above the right ear, the thyroid, midsternal level of the xiphoid, and the right side of the midsagittal plane of the chest.

Image acquisition

CT images were acquired using a GE Revolution Apex CT scanner (GE Healthcare, Waukesha, WI, USA). All scans were performed using standard clinical wrist protocols with scan parameters, as shown in [Table 1].

The scanner was calibrated according to department quality assurance protocols. 3D CBCT images were acquired in a 180° rotation around the forearm using a MultitomRax system [Figure 4] (Siemens Healtineers, Forchheim Germany) with 30 frames/s, 81 kV, and 2 mAs. All scans were repeated 5 times to allow averaging of dose measurements to account for any dose fluctuations.

Statistical analyses

Mean and standard deviation were calculated for all dose measurements for each phantom positioning and each anatomical region. Differences in radiation dose between the reference position (Superman pose), and all other phantom positions and image acquisition techniques were estimated using the one-way analysis of variance with Bonferroni correction, including 95% confidence intervals. $P \leq 0.05$ were considered statistically significant. SPSS statistical package version 27 (SPSS Inc. Chicago IL, USA) was used for statistical analyses.

RESULTS

The highest total dose (269.7 μGy) was obtained in helical CT with the forearm and wrist positioned on the abdomen. In comparison, the lowest total dose was achieved in single-shot CT with the phantom sitting behind the gantry with the forearm placed inside the gantry (3.2 μGy). Helical CT with the wrist positioned on the abdomen also resulted in the highest dose to the chest and ovaries, that is, 100.5 μGy and 91.0 μGy, respectively. In general, single-shot CT administered the lowest scattered radiation to the phantom. All dose measurements are presented in [Table 2], and differences between the reference (Superman pose) and alternative positions are listed in [Table 3].

DISCUSSION

In this phantom study, large differences in radiation doses between various patient positions were demonstrated with the "wrist on the abdomen" position resulting in a four-fold increase in total radiation dose, and the dose to the glabella and the xiphoid was substantially higher when the wrist was positioned on the abdomen. Thus, the radiation dose to sensitive organs such as eye lenses and breasts is a concern. While the xiphoid dose in the semi-superman position did not increase, the dose to the glabella increased markedly, and hence, other alternatives may be preferable. The "behind-gantry" single-shot CT resulted

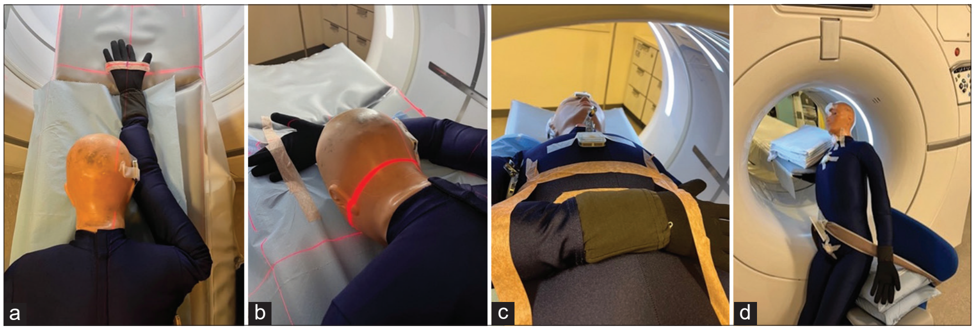

Figure 3: Phantom positions used in computed tomography (CT). (a) Superman pose, (b) semi-superman pose, (c) wrist on the abdomen, and (d) patient behind gantry.

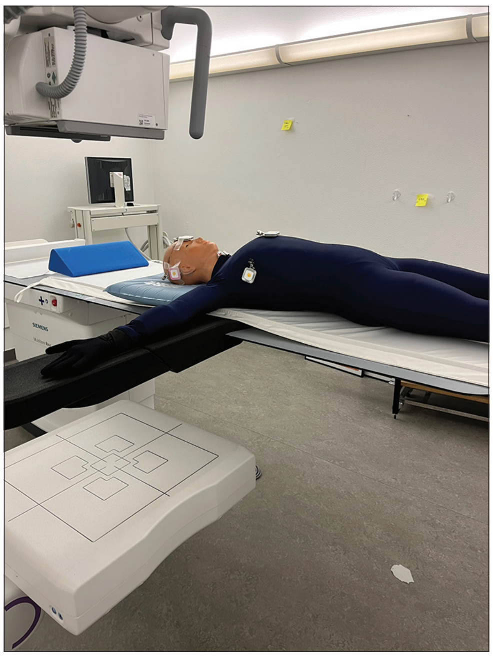

Figure 4: MultitomRax system (siemens healtineers, forchheim Germany).

Table 1: Acquisition parameters for the Computed tomography (CT) scan protocols.

Parameter	Helical CT	Single-shot CT
Tube voltage	100 kV	80 kV
Focal spot	Small	Small
Noise index	20	NA
Scan time	0.35 s	0.28 s
Pitch	0.516	NA
mA interval	30–30 ("Superman") 30–39 ("Semi-superman") 33–77 ("Wrist on abdomen")	65 fixed ("Superman") 65 fixed ("Front gantry") 65 fixed ("Behind gantry")
$CTDI_{vol}$	0.84 mGy ("Superman") 0.87 mGy ("Semi-Superman") 1.45 mGy ("Wrist on abdomen")	0.46 mGy ("Superman") 0.35 mGy ("Front gantry") 0.35 mGy ("Behind gantry")
Detector configuration	64×0.625 mm	256×0.625 mm
Kernel	Bone	Bone
ASIR-V*	30%	30%

$CTDI_{vol}$: Computed tomography dose $index_{volume}$, NA: Not applicable, *ASIR-V: Adaptive statistical iterative reconstruction, CT: Computed tomography

in a 95% total dose reduction compared to the reference superman position and may be preferable over the "front gantry" single-shot position that demonstrated the second lowest dose. However, both the "behind gantry" and "front gantry" position is challenging for the patient with decreased mobility and smaller size due to the gantry opening being deep, which is the case in GE scanners. In such cases, it may be better to use the Superman position in combination with single-shot CT, which demonstrates a radiation dose almost as low as the aforementioned positions and much lower than that of helical CT, as it eliminates the need for over-ranging. 3D CBCT exposed the phantom with nearly a three-fold increase in the total radiation dose compared to the reference (171.1 vs. 64.8 μGy), respectively. However, the 3D CBCT could be an alternative to the wrist-on-abdomen position. In 3D CBCT rooms equipped with floor or ceiling-mounted soft lead shielding, it would be possible to shield the patient's trunk and head exposing only the forearm to radiation. In that case, it may be possible to avoid a large amount of scattered radiation to the patient as the image acquisition only requires 180° rotation, and the scan is obtained with the arm extended away from the trunk. Furthermore, 3D CBCT presumably offers the most comfortable positioning option, also suggested by Grunz *et al.*[10] However, studies investigating the patients' perspective on the positioning are lacking.

The study design has limitations as the phantom soft tissue was not equivalent to human tissue. This was reflected in

Table 2: Mean radiation dose to various anatomical areas and patient positions using Helical CT, 3D CBCT, and single-shot CT. Radiation dose is presented in μGy, including standard deviation.

Phantom positioning	Glabella	Ear	Thyroid	Xiphoid	Chest lateral	Ovaries	Total dose
Superman pose (CT)	26.9 (1.9)	29.6 (2.0)	4.7 (0.2)	1.8 (0.1)	1.8 (0.1)	0.0 (0.0)	64.8
Semi-superman pose (CT)	49.7 (2.9)	60.0 (5.5)	6.9 (0.8)	2.3 (0.1)	2.2 (0.1)	0.0 (0.0)	121.1
Wrist on abdomen (CT)	4.2 (0.4)	2.4 (0.3)	12.4 (0.4)	59.2 (0.3)	100.5 (22.2)	91.0 (2.0)	269.7
3D CBCT	9.2 (0.5)	67.3 (0.9)	11.7 (0.3)	9.3 (0.5)	73.6 (0.3)	0.0 (0.0)	171.1
Superman pose (Single-shot CT)	3.9 (0.8)	2.9 (0.2)	0.4 (0.0)	0.3 (0.0)	0.2 (0.0)	0.1 (0.0)	7.8
Behind gantry (Single-shot CT)	0.2 (0.0)	1.9 (0.2)	0.2 (0.0)	0.1 (0.0)	0.6 (0.0)	0.2 (0.0)	3.2
Front gantry (Single-shot CT)	0.2 (0.0)	1.9 (0.0)	0.1 (0.0)	0.1 (0.0)	1.7 (0.0)	0.4 (0.0)	4.4

CT: Computed tomography, CBCT: Cone-beam computed tomography

Table 3: Mean differences, 95% confidence interval (CI), and *P*-values between radiation dose in the reference position (Superman pose CT) and all other positions.

Reference position	Comparative position	Anatomical region of dose measurement	Mean difference (95% CI)	*P*-value
Superman pose (CT)	Semi-superman (CT)	Glabella	22.8 (18.7–23.9)	<0.001
		Ear	30.5 (23.7–37.2)	<0.001
		Thyroid	2.3 (1.2–3.3)	<0.001
		Xiphoid	0.5 (0.2–1.1)	0.526
		Chest lateral	0.3 (−25.1–25.7)	1.000
		Ovaries	0.00 (2.3––2.3)	1.000
	Wrist on abdomen (CT)	Glabella	−22.7 (−26.8––18.6)	<0.001
		Ear	−27.1 (to−33.9––20.3)	<0.001
		Thyroid	7.7 (5.9–8.1)	<0.001
		Xiphoid	57.4 (56.7–58.1)	<0.001
		Chest lateral	98.6 (73.2–124.0)	<0.001
		Ovaries	91.0 (88.7–93.3)	<0.001
	3D CBCT*	Glabella	−17.7 (−21.8––13.6)	<0.001
		Ear	37.7 (−30.9–44.5)	<0.001
		Thyroid	7.0 (−5.9–8.1)	<0.001
		Xiphoid	7.5 (6.8–7.5)	<0.001
		Chest lateral	71.8 (46.4–97.2)	<0.001
		Ovaries	0.0 (−2.3–2.3)	1.000
	Superman pose (Single-shot CT)	Glabella	−23.0 (−27.1––18.9)	<0.001
		Ear	30.5 (23.7–37.2)	<0.001
		Thyroid	2.3 (1.2–3.3)	<0.001
		Xiphoid	−1.5 (−2.2––0.8)	<0.001
		Chest lateral	−1.6 (−27.0–23.8)	1.000
		Ovaries	0.1 (−2.2–2.4)	1.000
	Behind gantry (Single-shot CT)	Glabella	−26.7 (−30.8––22.5)	<0.001
		Ear	−27.6 (−34.4––20.8)	<0.001
		Thyroid	−4.5 (−5.6––3.4)	<0.001
		Xiphoid	−1.7 (−2.4––1.0)	<0.001
		Chest lateral	−1.2 (−26.7–24.1)	1.000
		Ovaries	0.2 (−2.1–2.5)	1.000
	Front gantry (Single-shot CT)	Glabella	−26.7 (−30.8––22.6)	<0.001
		Ear	−27.7 (−34.5––20.9)	<0.001
		Thyroid	−4.5 (−5.6––3.4)	<0.001
		Xiphoid	−1.7 (−2.4––1.0)	<0.001
		Chest lateral	−0.1 (−25.5–25.3)	1.000
		Ovaries	0.4 (−1.9–2.7)	1.000

*CBCT: Cone-beam computed tomography, 95% CIs: 95% confidence intervals, CT: Computed tomography lower computed tomography dose index$_{volume}$ ($CTDI_{vol}$) compared to Grunz *et al.*,[10] who found a $CTDI_{vol}$ = 3.3 mGy for the "Superman" position, while the present study demonstrated a $CTDI_{vol}$ = 0.84 mGy for the same position and slightly higher for the other arm positions. Thus, scattered radiation was probably somewhat underestimated, especially in the "wrist on abdomen" position. Furthermore, no image quality evaluation was performed; however, both modalities are well-established systems used in daily clinical practices. Grunz *et al*. reported that although the image quality of 3D CBCT wrist scans was inferior to that of multidetector CT (MDCT), the 3D CBCT images were found to be of a quality well-suited for diagnostic use.[10]

CONCLUSION

The results of the present study indicate that the often-applied wrist-on-abdomen position in CT may not be recommended when either single-shot CT or 3D CBCT is available, given that image quality is deemed sufficient locally. Furthermore, when available, single-shot CT should be considered and will be most patient-friendly in an upright position in front of or behind the scanner gantry. Finally, the authors recommend that radiographers carefully consider alternatives when a patient referred for wrist CT is incapable of complying with the Superman position.

Ethical approval

The Institutional Review Board approval is not required.

Declaration of patient consent

Patient's consent was not required as there are no patients in this study.

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Nil.

Conflicts of interest

There are no conflicts of interest

Use of artificial intelligence (AI)-assisted technology for manuscript preparation

The authors confirm that there was no use of artificial intelligence (AI)-assisted technology for assisting in the writing or editing of the manuscript and no images were manipulated using AI.

REFERENCES

1. Mauck BM, Swigler CW. Evidence-based review of distal radius fractures. Orthop Clin North Am 2018;49:211-22.
2. Nellans KW, Kowalski E, Chung KC. The epidemiology of distal radius fractures. Hand Clin 2012;28:113-25.
3. Porrino JA, Maloney E, Scherer K, Mulcahy H, Ha AS, Allan C. Fracture of the distal radius: Epidemiology and premanagement radiographic characterization. Am J Roentgenol 2014;203: 551-9.
4. Jensen J, Tromborg HB, Rasmussen BS, Gerke O, Torfing T, Precht H, *et al*. The effect of forearm rotation on radiographic measurements of the wrist: An experimental study using radiostereometric analyses on cadavers. Eur Radiol Exp 2021;5:15.
5. Jensen J, Tromborg HB, Rasmussen BS, Gerke O, Torfing T, Prechet H, *et al*. Dorsal tilt of the distal radius fracture changes with forearm rotation when measured on radiographs. J Hand Surg Glob Online 2021;3:182-9.
6. Athlani L, Chenel A, Berton P, Detammaecker R, Dautel G. Three-dimensional versus radiographic measurements for analyzing extra-articular distal radius malunion. J Hand Surg 2020;45:984.e1-7.
7. Hughes J, Harris M, Snaith B, Benn H. Comparison of scattered entrance skin dose burden in MSCT, CBCT, and X-ray for suspected scaphoid injury: Regional dose measurements in a phantom model. Radiography (Lond) 2022;28:811-6.
8. Brink M, Steenbakkers A, Holla M, de Rooy J, Cornelisse S, Edwards MJ, *et al*. Single-shot CT after wrist trauma: Impact on detection accuracy and treatment of fractures. Skeletal Radiol 2019;48:949-57.
9. Grunz JP, Weng AM, Kunz AS, Veyhl-Wichmann M, Schmitt R, Gietzen CH, *et al*. 3D cone-beam CT with a twin robotic x-ray system in elbow imaging: Comparison of image quality to high-resolution multi-detector CT. Eur Radiol Exp 2020;4:52.
10. Grunz JP, Gietzen CH, Kunz AS, Weng AM, Veyhl-Wichmann M, Ergün S, *et al*. Twin robotic X-ray system for 3D cone-beam CT of the wrist: An evaluation of image quality and radiation dose. Am J Roentgenol 2020;214:422-7.
11. Inaba Y, Chida K, Kobayashi R, Kaga Y, Zuguchi M. Fundamental study of a real-time occupational dosimetry system for interventional radiology staff. J Radiol Prot 2014;34:65-71.

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